neither consuming nor ...

10.3 Transport in Plants

The movement of materials into the body, within the body and out of the body of the organism is called transport. In plants the examples of transport are absorption of water and minerals from the soil through roots and the movement of organic solutes from leaves to different parts of the plants.

10.3.1 Movement of water between plant cells and their environment

The movement of water between plant cells and their environment takes place by osmosis. **Osmosis** is the movement of water from a region of higher water concentration towards lower water concentration through a semipermeable membrane. The absorption of water from soil to roots is example of osmosis in plants. If water moves into the cell by osmosis then it is called endosmosis and if water moves out of the cell then it is called exosmosis.

Water relations of the cells:

On the basis of movement of water into and out of cell, there are three kinds of water relations, i.e., water potential, solute potential and pressure potential.

Water potential:

The total kinetic energy of water molecules due to which they move from place to place is called water potential. The greater concentration of water molecules in a system, the greater is the kinetic energy of water molecules. The potential is denoted by a Greek symbol Ψ (Psi), so water potential is denoted by Ψw. The Potential is expressed in the unit of pressure called Pascal (Pa).

Two factors determine the water potential in plants:

i) Solute concentration, i.e., osmotic potential of solute (Ψs)

ii) Pressure polential (Ψp) so $\Psi w = \Psi s + \Psi p$

Pure water has maximum water potential. Thus water potential is zero. By definition water molecules always move from a region of higher water potential to a region of lower water potential.

> **Critical Thinking**
>
> *Do you know why we usually water plants in the morning or evening but not in the afternoon?*

Applications of water potential:

There are following applications of water potential.

i) Water potential can be used to measure the tendency of water to move between any two systems.

ii) Water potential can also be used for movement of water from soil to roots, from leaf to air, from air to soil.

The following example will help to understand the concept of water potential. Two adjacent vacuolated cells are shown with Ψw, Ψp, Ψs. The kPa = 1000 pascal.

Example

Cell A		Cell B	
Ψw	= -1400 kPa	Ψw	= -600 kPa
Ψs	= 600 kPa	Ψs	= 800 kPa
Ψp	= -2000 kPa	Ψp	= -1400 kPa

Qusestions

- Which cell has higher water potential?
- In which direction will water move by osmosis?

- What will be the water potential of the cell at equilibrium?
- What will be the solute potential and pressure potential of the cell at equilibrium?

Solute potential: (Osmotic potential):

The change in water potential of a system due to addition of solute is called osmotic potential or solute potential. **Solute potential** is always negative, i.e., with increase in solute the osmotic pressure will also increase. **Osmotic pressure** is an important factor affecting cells. In hypotonic solution the cell gets swell, in hypertonic solution the cell gets shrink while in isotonic solution the cells retain their shape and size.

Pressure potential (Ψp):

The pressure exerted by the protoplast against the cell wall of plant cell is called pressure potential. Water potential increases when pressure greater than atmospheric pressure is applied on pure water solution. It is equivalent to pumping water from one plant to another. Such situation may arise when in living cells the water enters into plant cell by osmosis. This water builds up pressure inside the cell and make the cell turgid. It also increases the pressure potential. The pressure potential helps to maintain the shape of the cell.

10.3.2 Uptake of Water by Roots and Pathways

The root hairs are located on the edge of the roots while xylem vessels are in the center. Before the water can be taken to the rest of the plant, it must reach to xylem vessels through root hairs. There are following three pathways taken by water to reach the xylem vessels.

a. Apoplast pathway
b. Symplast pathway
c. Vacuolar pathway

Apoplast pathway:

The movement of water through the extra cellular pathway between the cell walls of adjacent cells is called apoplast pathway. The ions easily reach the endodermis by this

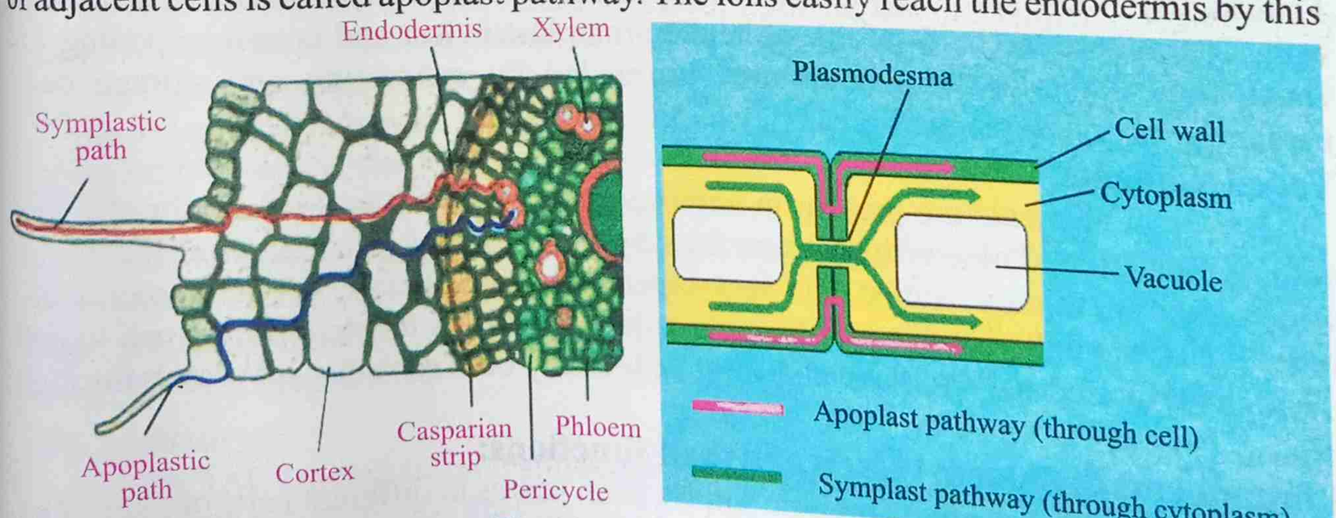


Fig. 10.3 Pathway of water

pathway, but the **casparian strips** prevent further movement. The casparian strip is a band of cell wall material deposited in the radial and transverse walls of root endodermal cells. It is chemically composed of suberin (a water proof waxy substance). Thus these ions must enter into the endodermal cells by diffusion or active transport. They enter into cytoplasm or vacuole of the endodermal cells.

Symplast pathway: The movement of cell sap through the plasmodesmata of cell is called symplast pathway. **Plasmodesmata** (singular plasmodesma) are cytoplasmic microscopic channels between cell walls of adjacent plant cells which enables transport and communication between them. There is a concentration gradient down the cells of cortex, endodermis, pericycle and sap of xylem so minerals move down through plasmodesmata into the cells of cortex, endodermis, pericycle and then to the sap of xylem.

The vacuolar pathway: The movement of water molecules in plant cells via the vacuoles located in the cytoplasm of the cell. The water molecules encounter high resistance and as a result little flow usually occurs, making this pathway less efficient than apoplast and symplast pathway. Water moves by osmosis across the vacuoles of the cells of root system.

10.3.3 Structure and Function of Xylem and Phloem

Xylem and phloem are two types of transport tissues in vascular plants. The basic function of xylem is to transport water from roots to shoots and leaves but also transport some nutrients. The phloem transports organic food from photosynthetic cells to all parts of plants for use and storage.

Components of xylem: The word xylem is derived from the Greek word *"xylon"* meaning wood. These are elongated cells and tubular water transport system because these cells are connected end to end with each other. There are two main kinds of cells in xylem, i.e. Tracheids and Vessel elements.

Tracheids: Tracheids are elongated cells up to 80 nm wide with secondary lignified cell wall. The mature tracheids are dead hence protoplast is lost and creating opening for water flow. Functional tracheids are surrounded by supporting and storage cells paraenchyma, sclereids and fibres.

Vessel elements:

Vessel elements are present in angiosperms. These are specialized for efficient water conduction. These reduce water loss by transpiration. The vessel elements are wider, shorter, thinner walled and less tapered than tracheids. Vessel elements are individual cells linked end to end froming xylem vessel. Water stream from cell to cell through perforated end walls and also migrate laterally between adjacent vessels through pits.

Components of phloem vessels and their functions:

The phloem transports organic solutes from leaves to different parts of plant. The phloem tissue is present on outside of xylem tissue. The phloem is a permanent tissue that

is composed of three living cells and one dead cell. The living cells are sieve tube elements, companion cells and the phloem parenchyma while the dead cell is sieve tube. The **sieve tube** are long elongated cells placed end to end with the walls composed of cellulose. The end walls of sieve tubes are perforated. The perforated area looks like a sieve thus known as sieve plate. These pores of sieve tube help in translocation of solutes. The **companion** cells are thin walled elongated cells associated with sieve tube. These are living cells containing cytoplasm and elongated nucleus. The companion cell and sieve tube are in communication with each other through plasmodesmata. The companion cells provide energy to sieve tubes. The phloem tissue also possesses parenchyma that has storage function and very thick walled fiber cells which provide support.

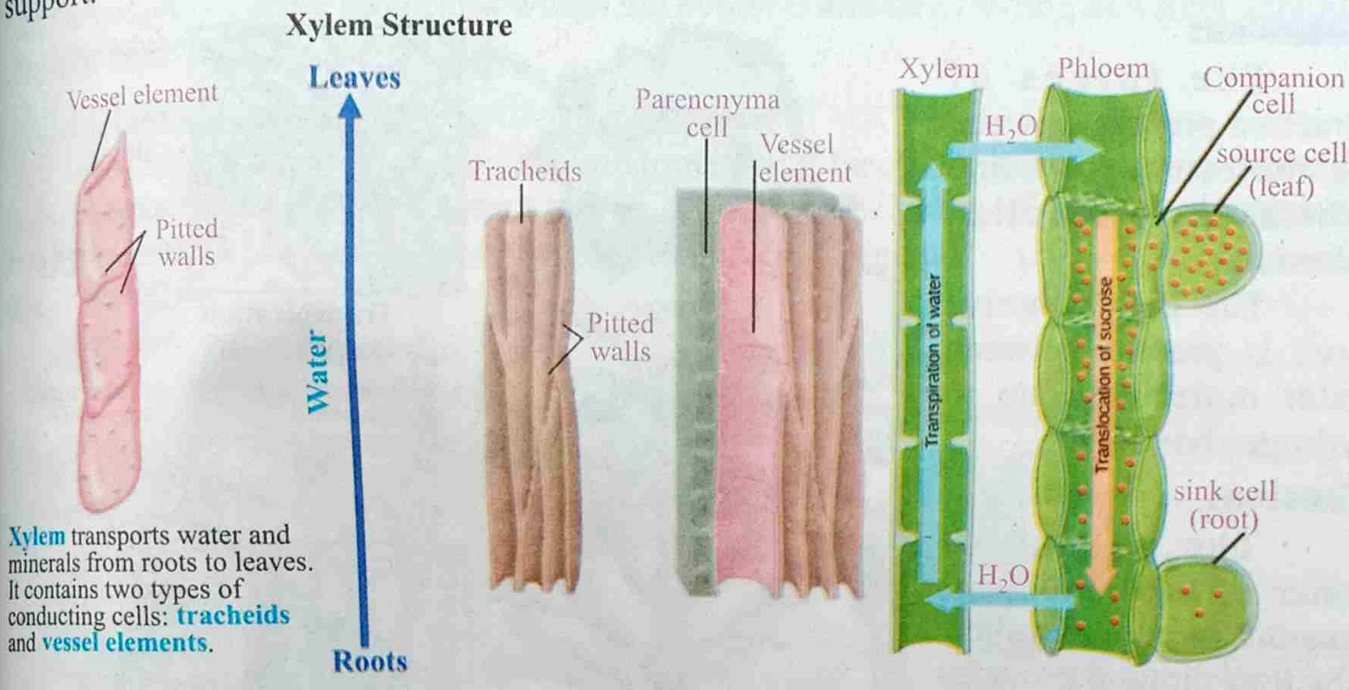


Fig.10.4 Structure of Xylem and phloem

10.3.4 Ascent of sap

The pull of water and dissolved minerals through the xylem tissue towards the leaves is known as ascent of sap. The water and dissolved minerals are collectively called sap and ascent means upward movement. Dissolved minerals from soil enter in root hairs and then move through the following path ways:

Epidermis ⟶ cortex ⟶ endodermis ⟶ pericycle ⟶ xylem ⟶ leaves

As the ascent of sap is against the gravity, therefore, a considerable force is required to transport the sap especially in tall plants. The sap is transported from roots to leaves through xylem by TACT forces. These TACT forces also known as TACT theory, responsible for ascent of sap.

TACT theory:

The TACT stands for Transpiration pull, Adhesion, Cohesion, Tension. The ascent of sap through "these forces" are called TACT theory.

Transpiration pull:

The transpiration involves in the pulling of water upward by utilizing the energy of evaporation. Transpiration pulls the water at much higher speed (upto 8 m/h). About 99% of pulled water is transpired while remaining 1% is used for various activities like photosynthesis.

Adhesion:

The force of attraction between the water molecules and other substances is called adhesion. The water and cellulose are polar molecules, therefore, strong attractive forces are present between water and cellulose, so the water molecules adhered to xylem tissue and column of water does not break.

Cohesion:

The forces of attraction present between the molecules of same substances are called cohesion.

The high cohesive force is present between water molecules due to hydrogen bonding.

Tension:

The pulling of water upward produces tension in xylem tubes. The transpiration provides the necessary energy. The hydrogen bonds between water molecules produce this tension. In xylem water tension is much stronger. It can pull the water upto 200 m (more than 600 feet) in plants.

Mechanism of TACT force:

The evaporation of water from the aerial parts of plants especially through stomata of leaves is called **transpiration.**

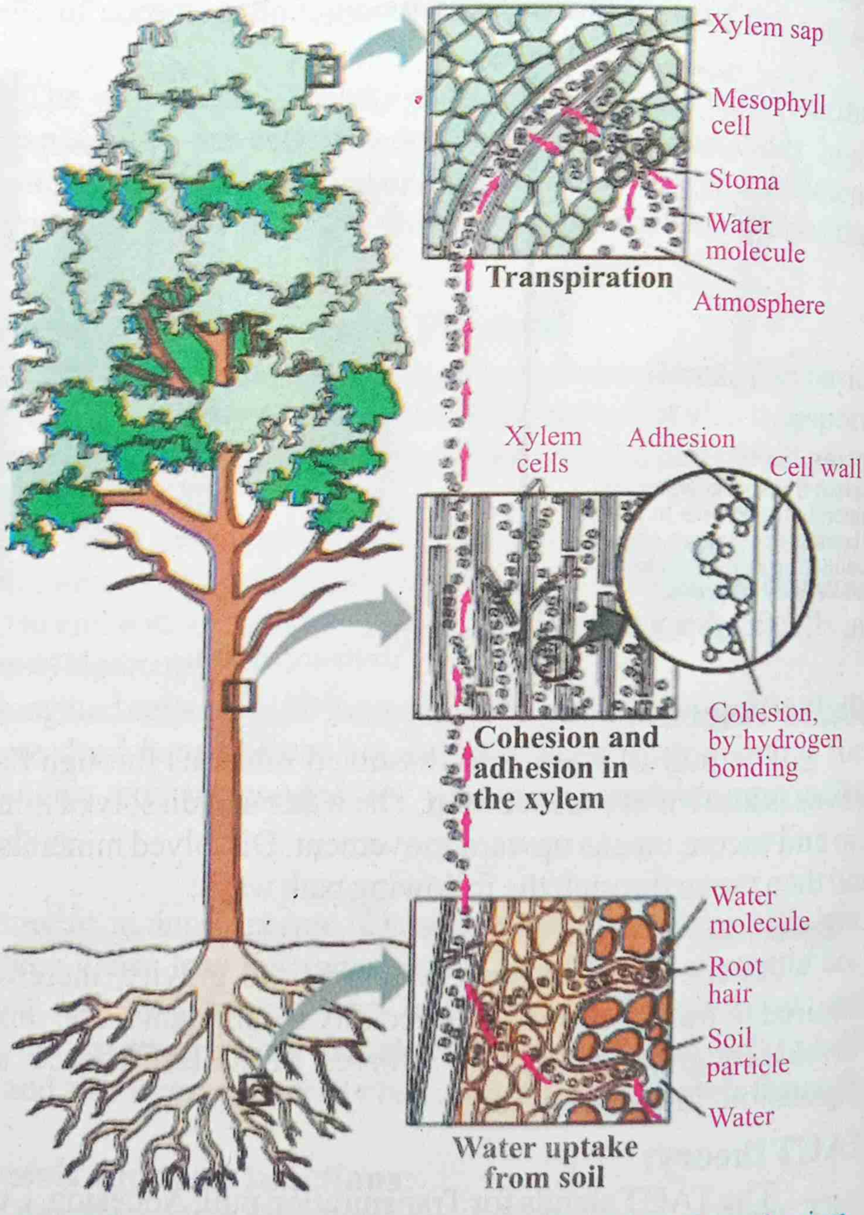


Fig. 10.5 Movement of water in xylem through TACT mechanism

Due to transpiration water potential of mesophyll cells drops which causes water to move by osmosis from xylem cells of leaf into dehydrating mesophyll cells. The water molecules leaving the xylem are attached to other water molecules in the same xylem tube by hydrogen bonds (cohesion of water molecules), therefore, when one water molecule moves in the xylem, the process continues all the way to the roots where water is pulled from xylem.

> **Tit bits**
> *The combination of adhesion. cohesion and surface tension allow water to climb upward. It is called capillary action.*

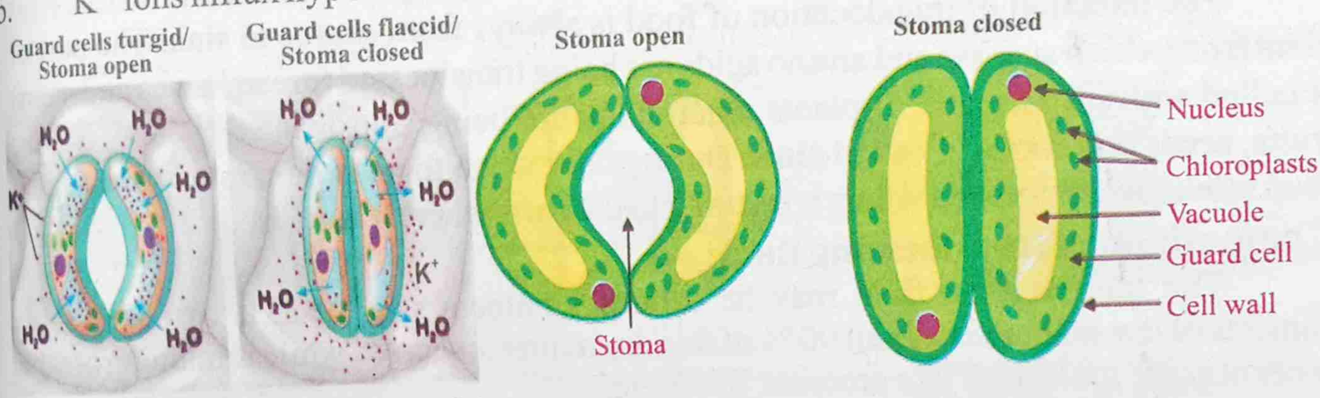
This pull also causes water to move down its concentration gradient transversely from root epidermis (root hairs) to the cortex endodermis and to pericycle. It is estimated that the column of water molecules within the xylem is atleast as strong as a steel wire of the same diameter.

10.3.5 Opening and closing of stomata

As discussed earlier in this chapter stomata are the openings between two guard cells. The guard cells play important role in opening and closing of stomata. There are two hypothesis for explaining the opening and closing of stomata.

a. Starch sugar hypothesis.

b. K^+ ions influx hypothesis.



(b) Role of potassium in stomatal opening and closing

Fig. 10.6 Opening and closing of stomata.

a. Starch sugar hypothesis:

This hypothesis was proposed by German botanist Hugo von Mohl. According to this hypothesis the guard cells are the only photosynthesizing cells of leaf epidermis because they have high contents of chlorophyll than the surrounding epidermal cells.

Opening of stomata: Photosynthesis takes place during day time so sugar is produced in the guard cells during day time. The increase in sugar level increases the solute concentration in the cell. Therefore, water potential in the cell decreases. As a result the guard cells absorb water and become turgid and curved. This creates an opening in stoma.

Closing of stomata: The process of photosynthesis slows down at night. The already present sugar is utilized in respiration or stored in the form of insoluble starch. So the

osmotic potential of guard cells is higher. Thus water leaves the guard cells, they become flaccid and stomata are closed.

b. K^+ ions influx hypothesis:

According to this hypothesis when photosynthesis starts in morning, this causes a decrease in level of CO_2 in guard cells. The low level of CO_2 stimulates the inward movement of K^+ ions into the guard cells.

Opening of stomata: The accumulation of K^+ ions in guard cells decreases the osmotic potential so water enters the guard cells by osmosis. As a result guard cells become more turgid so stomata are opened.

Closing of stomata: The stomata close by reverse process. There is a passive diffusion of K^+ ions from guard cells to outside so water also moves out by osmosis. The guard cells become flaccid and close the stomata. The level of CO_2 in the space inside the leaf and light control the movement of K^+ ions into and out of guard cells.

10.3.6 Translocation of organic solutes

The movement of sucrose and amino acids in phloem, from region of production to region of storage or to regions of utilization is called translocation of organic solutes.

Pattern or direction of translocation:

The direction of translocation of food is always from source to sink. The part of plant from which sucrose and amino acids are being translocated (green leaves and stem) is called **source.** The part of plants where they are being translocated (yellow leaves, fruits, seeds and roots) is called **sink.** During cold when there is no photosynthesis, the food moves from the parts where it is stored to the parts where it is utilized.

Composition of translocating fluid:

The translocating fluid may be called as phloem sap. 10-25% of phloem sap consists of dry matter and about 90 % of this dry matter is sucrose while remaining are the other organic molecules like proteins, lipids etc.

Mechanism of translocation:

There are different views about the mechanism of translocation but most acceptable one is pressure flow or mass flow theory.

Pressure flow theory:

Ernst Munch proposed a hypothesis in 1927 to explain the mechanism of translocation. This hypothesis states that an osmotically generated pressure gradient between source and sink drives the solution through the **sieve elements.** Now this hypothesis has been given the status of theory. The pressure flow theory accounts for the mass movement of molecules within phloem. It may be noted that carbohydrates from the mesophyll cell to phloem tissue involve diffusion and active transport. Then in phloem tissue the movement of materials takes place in bulk and according to the pressure flow mechanism.